Higgs production and other Two-Photon Processes in eA Collisions at HERA energies

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Abstract: The planed HERA upgrade will increase the integrated luminosity by two orders of magnitude. A new program of electron-nucleus collisions at HERA is under discussion now. In this connection we present prospects for the study of a light neutral Higgs boson, SUSY-particle, hadrons and leptons production in the two-photon coherent eA collisions at HERA energies.

1   Introduction

Particle production in the two-photon processes in lepton-lepton, hadron-hadron and nucleus-nucleus collisions has been already discussed in the literature [1]-[5]. One of the goals of the present analysis is to study the discovery potential of electron-nucleus collisions at HERA in the case of coherent electromagnetic particle production.

Requirement of coherency implies that the collision is quasi-elastic, the impact parameter b is larger than the nuclear radius and the nuclear charge acts as a whole. For such collisions the hadronic background from $\gamma^* q$ and $\gamma^* g$ (direct and resolved) subprocesses will be absent offering a better experimental environment for studying new particle production.

Due to the large charge Z of heavy ion and the strong contraction of the electromagnetic fields in a high-energy collision we expect in such an electron-nucleus interaction a large particle production rate by the two-photon fusion mechanism. It turns out that the cross sections, which is scale with Z^2, are comparable or even large than the total cross sections expected in e^+e^-, ep and pp collisions of the same incident energy per particle.

An important characteristic of eA collider is it discovery range: how heavy produced particles can be and how large will be production cross sections for them. In the equivalent photon approximation the invariant mass squared of the two-photon system, denoted by W^2, is fixed by the photon energies ω_e and ω_A. As it well known [4], [5] that the time duration of the electromagnetic pulse, produced by a charge moving with a relativistic γ factor, corresponds to field frequencies of $\omega \leq \gamma/b$. In the case of a heavy-ion beam the largest photon energy is $\omega_A \simeq \gamma_A/R_A$ although for photons emerged from an electron beam the photon energy can be close to the electron energy $\omega_e \leq E_e$. Thus the discovery range of the eA HERA collider for coherent processes extends to masses:

$$W \approx (4\omega_e\omega_A)^{1/2} \leq \left(\frac{4\,E_e E_p}{m_p R_A}\right)^{1/2} . \tag{1}$$

This means the invariant mass values accessible at HERA energies are up to 86 GeV, 71GeV and 54 GeV for eC, eCa and ePb collisions, respectively.

The paper is organized as follows: In the next section we compare the discovery ranges of eA (HERA), e^+e^- (LEP2) and ep (HERA) colliders using the two-photon luminosity function . In Sect.3, we evaluate cross sections for coherent production of lepton and slepton pairs (e^+e^-, $\mu^+\mu^-$, $\tau^+\tau^-$, $\tilde{l}^+\tilde{l}^-$), charged pion pair, pseudoscalar ($J^C = 0^+$) resonances and the MSSM light Higgs boson. Conclusions are given in the last section.

2 Two-photon luminosity function

The equivalent photon approximation is allow to express the cross section for the two-photon production processes in eA collisions as follows [1], [2]

$$d\sigma_{eA} = \sigma_{\gamma\gamma}dn_e dn_A \tag{2}$$

where dn_i is the number of equivalent photons, or a distribution in photon frequencies. It is convenient to define [7] a dimensionless quantity $L_{\gamma\gamma}$ called the two-photon luminosity (TPL)

$$dL_{\gamma\gamma} = \int dn_e(x_e) dn_A(x_A)\delta(z^2 - x_e x_A), \tag{3}$$

where $z = W/\sqrt{s_{eA}}$ and $x_i = 2\omega_i/\sqrt{s_{eA}}$. Function $L_{\gamma\gamma}$ depends on the type of colliding particles and Lorentz invariant quantities and is very useful for comparing the relative efficiency of the different colliders[1].

Let to calculate the TPL function in the center of mass of colliding an electron and heavy-ion. If we integrate eq. (3) over the energy range of one of the photons $t^* \le x_e \le 1$ with the photon spectra

$$dn_e = \frac{\alpha}{2\pi}[1 + (1 - x_e)^2] \ln\frac{s}{4m_e^2}\frac{dx_e}{x_e} \tag{4}$$

of an electron [6], [1] and

$$dn_A = \frac{2Z_A^2\alpha}{\pi} \ln\frac{\gamma_A}{\omega_A R_A}\frac{dx_A}{x_A} \tag{5}$$

of an ion [4] we obtain the following expression for the differential two-photon function:

$$\frac{dL_{\gamma\gamma}}{dW} = \frac{2Z_A^2\alpha^2}{\pi}\frac{f(t^*)}{W} ln\left(\frac{s_{eA}}{4m_e^2}\right), \tag{6}$$

where

$$f(t^*) = (\ln t^* + \frac{\sqrt{3}}{2})^2 + (t^* - 4)^2 - 3$$

and $t^* = \frac{R_A\sqrt{s_{eA}}}{2\gamma_A} z^2$. Eq. (6) is valid in the leading logarithm approximation.

Thus the differetial cross section for the production of a final state with the effective mass W in the two photon eA collision is a product

$$d\sigma_{eA} = \sigma_{\gamma\gamma} \cdot \frac{dL_{\gamma\gamma}}{dW}dW \tag{7}$$

of the cross section $\sigma_{\gamma\gamma}$ of the $\gamma\gamma \to f$ transition for real non-polarized photon and the TPL function.

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[1] To get the production rate Eq. (2) have to be multiplied by the machine luminosity $\mathcal{L}_{eA}$ $[cm^{-2}sec^{-1}]$. For ion beams $\mathcal{L}_{eA} \sim A^{-1}\mathcal{L}_{ep}$.
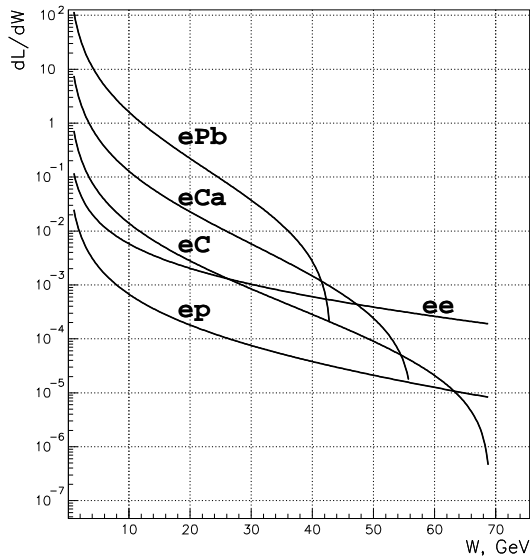
Figure 1: *Spectra of the two-photon luminosity function for e^+e^- (LEP, 200 GeV), ep(HERA, 300 GeV), and eA (HERA, 300A GeV) colliders.*

In Fig. 1 shown the dependence of TPL on the two-photon invariant mass for different colliding beams. The TPL function for e^+e^- (LEP2) was calculated with using Eq.(6) of ref. [7], as for the ep collision (HERA) the elastic part of the photon spectra from the proton was taken from [8]. Because of the used approximation the range of allowed W values in (6) is narrow (see Fig.1) as compared to (1) and defined by the condition $f(t^*) \geq 0$.

The advantage of eA collisions over e^+e^- and ep collisions lies in the Z^2 factor, which enchances the photon flux up to a factor 10^4. This allow, in the range of W below 40 GeV, the study of 'new phenomena' at HERA with large statistics. Results presented here were obtained for untagged scattered electron and nucleus. The effect of the nuclear formfactors on the TPL function is not included.

3   Particle production processes

In this section we present a few examples of particle production in eA collisions through the two-photon mechanism. Processes with production of the 'old' particles (light hadrons and leptons) will create a background at search of 'new' particles (like Higgs bosons and sleptons). Cross sections presented here were calculated at $E_e = 27\,\text{GeV}$ and $E_A = E_p A$ with $E_p = 820\,\text{GeV}$.

Resonances and pions

A region of the low mass in the two-photon system is the resonance region. C-even pseudoscalar hadrons - π^0, η, $\eta^{'}$, η_c, χ_{c0} - will be produced copiously at $W < 4\,\text{GeV}$. Their production cross section $\sigma_{\gamma\gamma}$ is well known [1]

$$\sigma_{\gamma\gamma \to R} = 8\pi \frac{\Gamma^{\gamma\gamma}\Gamma}{(W^2 - m_R^2)^2 - \Gamma^2 m_R^2} \tag{8}$$

and expressed through the two-photon decay width $\Gamma^{\gamma\gamma}$ of the resonance R. Now Eqs. (7) and (6) allows easily to evaluate dependence of the production rate on W. Fig. 2a shows a resonance structure of the differential cross section (7) in that region.

As another example the cross section (7) for pair production of charged pions is plotted in Fig. 2b. The corresponding total $\gamma\gamma \to \pi^+\pi^-$ cross section in Born approximation (pointlike pions) [1] is

$$\sigma_{\gamma\gamma} = \frac{2\pi\alpha^2}{W^2} \left[\left(1 + \frac{4m_\pi^2}{W^2}\right) \sqrt{1 - \frac{4m_\pi^2}{W^2}} - \frac{8m_\pi^2}{W^2} \left(1 - \frac{2m_\pi^2}{W^2}\right) \ln \left(\frac{W}{2m_\pi} + \sqrt{\frac{W^2}{4m_\pi^2} - 1} \right) \right]. \tag{9}$$
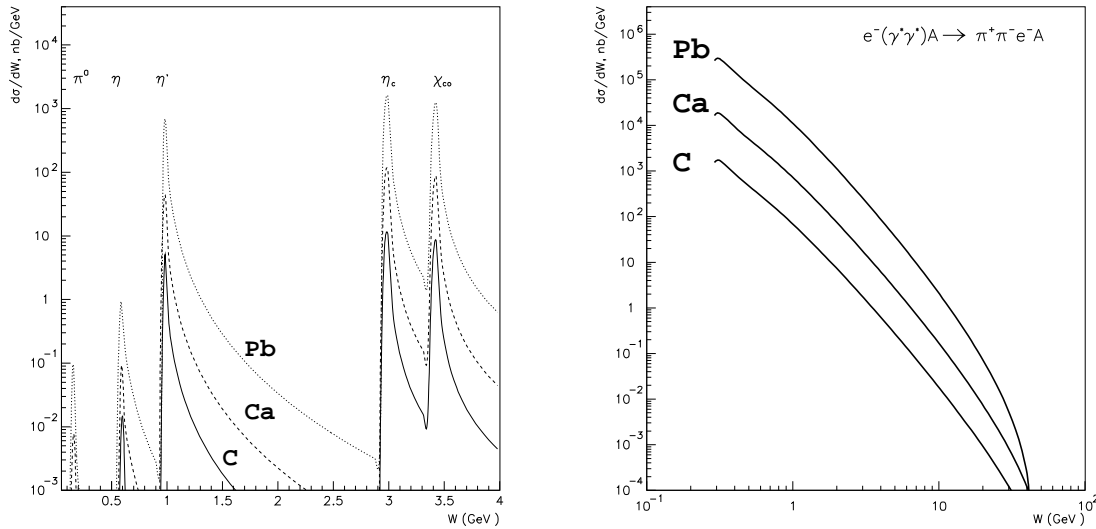
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Figure 2: *Differential cross section for production of C-event pseudoscalar hadrons (a) and a $\pi^+\pi^-$ pair (b) as a function of W and a nucleus size.*

In [1] is also discussed in details what can be measured in the above processes and how. We note only, that the study of the angular and energy correlations between pions allows, in principle, to extract components of the amplitude $M_{ab}(a, b = +, -, 0)$ for the $\gamma\gamma \to f$ transition.

Lepton pairs

The Bethe-Heitler process is a source of lepton pairs with extremely high yield (Fig. 3). Including the mass effects at the threshold, the cross section [1] for producing a pair of identical leptons is

$$ \sigma_{\gamma\gamma} = \frac{4\pi\alpha^2}{W^2} \left[2\left(1 + \frac{4m_l^2}{W^2} - \frac{8m_l^4}{W^4}\right) \ln\left(\frac{W}{2m_l} + \sqrt{\frac{W^2}{4m_l^2} - 1}\right) - \left(1 + \frac{4m_l^2}{W^2}\right)\sqrt{1 - \frac{4m_l^2}{W^2}} \right], \quad (10) $$

where m_l is the lepton mass. Copious production of τ-leptons provide an opportunity to study QCD in τ decay [9]. However it will also to complicate the Higgs boson search in lepton decay modes because the main background above the τ threshold is due to $\gamma^*\gamma^* \to \tau^+\tau^-$. How to suppress the Bethe-Heitler background is discussed in [10] .

SUSY particles

Non-strongly interacting sypersymmetric particles - sleptons and charginos- can be detected at the eA collider discussed here if their masses lies in the range $M_{sl} < 30$ GeV. Chargino couple to photons in the standard way of spin 1/2 fermions and sleptons are spin-zero particles. The two-photon cross sections for production a pair of them [11] are coincide with eqs. (10) and (9), respectively. $\sigma(\gamma\gamma \to \tilde{l}^+\tilde{l}^-)$ is not logarithmically enhanced thus the production rate for sleptons is significantly lower than the chargino rate. As an example , the total cross section for slepton production versus the mass of the produced particle is shown in Fig. 4a. At an integrated luminosity of $10^3/A\,\mathrm{pb}^{-1}$ only sleptons with masses not heavier 29 GeV, 25 GeV and 20 GeV can be detected in eC, eCa, ePb collisions respectively. At $\mathcal{L}_{eA} \sim 1/A\,\mathrm{pb}^{-1}$ the discovery range for sleptons shrinks to $M_{\tilde{l}} < 13$ GeV.
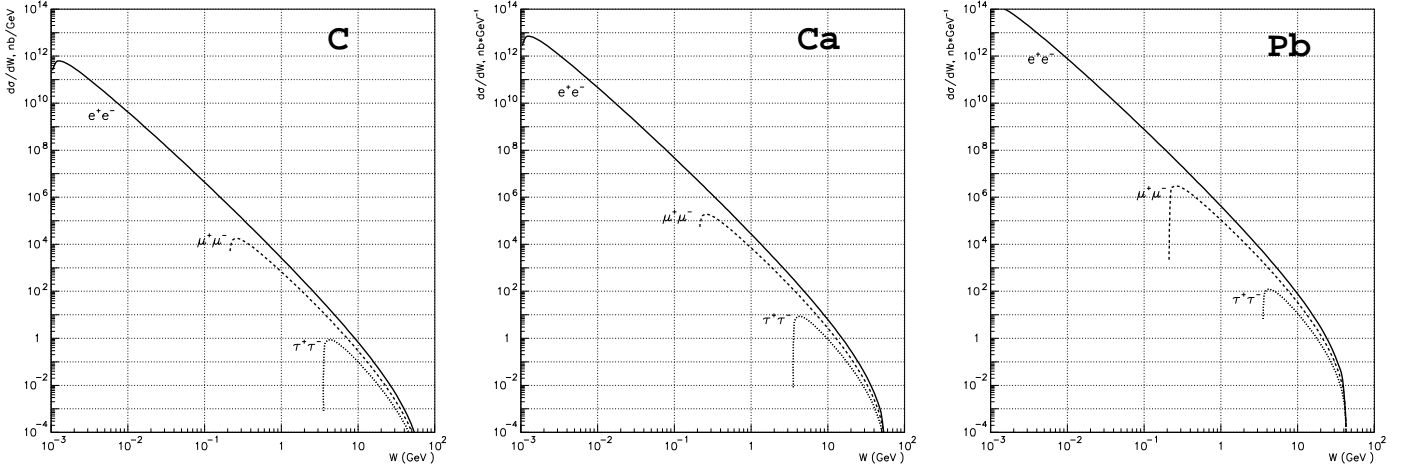
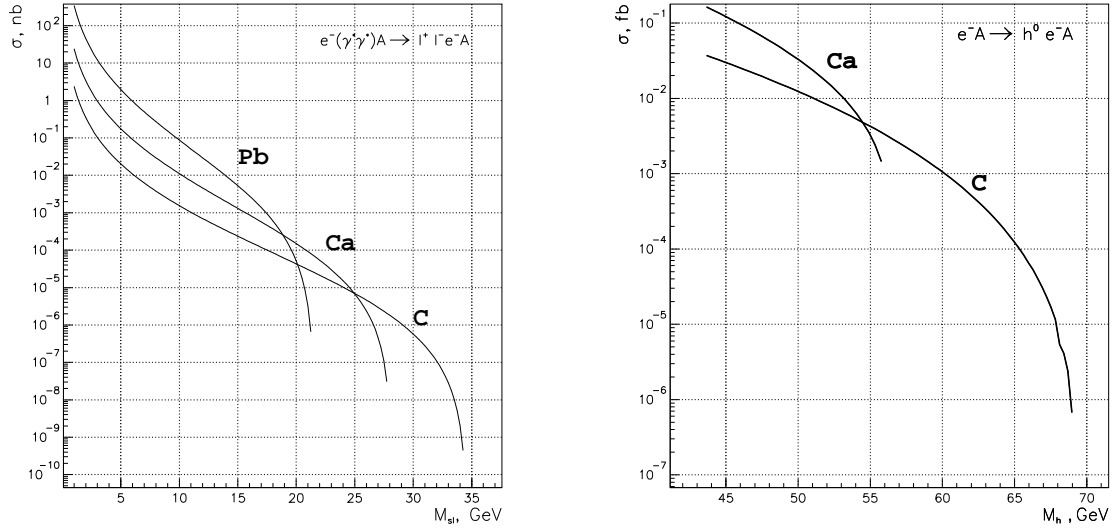Figure 3: *Same as Fig. 2 for production of BH leptons in coherent eA collisions.*

Figure 4: *Cross sections for slepton (a) and MSSM light Higgs boson ($\tan \beta = 1.75$) (b) production through two-photon fusion. The cross sections are plotted versus the mass of the produced particle.*

Light CP-even Higgs boson

In the Minimal Supersymmetric Standard Model (MSSM) there is correlation between the top quark mass and the ratio of the vacuum expectation values, $tan\,\beta = v_2/v_1$[12]. For the top mass in the range between 150 and 200 GeV theoretically favored value of $tan\,\beta$ is $\sim$1.7 [13]. At M_t =172 GeV (the central value) the upper limit on the mass of the lightest CP-even Higgs boson h is [14]

$$M_h \lesssim 124\,GeV\,.$$

The current LEP data restrict M_h from below to the value 45 GeV. A part of this mass range hits to the HERA discovery range (1) and therefore let us estimate the cross sections for production h in the two-photon coherent eA collisions.

To calculate the total cross section of h production it is necessary to integrate eq. (7) over

W in the range

$$2M_h < W < \sqrt{\frac{s_{ep}}{m_p R_A}}$$

with $\sigma_{\gamma\gamma}$ from (8). Values of the partial decay widths $h \to \gamma\gamma$ can be calculated with the program HDECAY [15]. In Fig. 4b presented the cross sections versus the Higgs boson mass. At a realistic integrated luminosity of the order $1/A$ pb^{-1} and even two order higher the values of the cross sections are far beyond the HERA sensitivity.

4   Conclusions

Analysis of the last section shows that in the two-photon coherent eA collisions a number of the traditional processes (with hadron and lepton production) can be studied at HERA with high statistics. However, only the restricted mass range $M_{\tilde{l}} < 13$ GeV can be explored in processes with SUSY particle production. Processes with production of MSSM Higgs particles will be unaccessible for study at the planed HERA luminosity.

The last chance to study the Higgs bosons at HERA provide [16] the general two doublet model (2HDM) [12], since in framework of 2HDM light neutral Higgs particle is not rule out by present data. Analysis of the light PC-even Higgs boson production in the two-photon eA interactions will be performed elsewhere [17].

References

[1] V.M. Budnev, I.F. Ginzburg, G.V. Meledin, V.G. Serbo, Phys. Rep. **C15** (1975) 181

[2] P. Kessler, Acta Phys. Austriaca, 41 (1975) 141

[3] J.H. Field, in *Lecture Notes in Physics*: Photon Photon Collisions, v. 191 (1983) 270

[4] G. Baur, C.A. Bertulani, Phys. Rep. **C163** (1988) 299

[5] E. Papageorgiu, Nucl. Phys. **A498** (1989) 593c; Phys. Rev. **D40** (1989) 92

[6] F. Low, Phys. Rev. **120** (1960) 582

[7] J.H. Field, Nucl. Phys. **B168** (1980) 477

[8] N. Arteaga-Romero, C. Carimalo, P. Kessler, Z. Phys. **C52** (1991) 289

[9] G. Altarelli, QCD at Colliders, Preprint CERN-TH-95/196;
Proceedings of tau '94, Nucl. Phys. **B(Proc.Suppl.)** (1995) 1

[10] P.J. Bussey, B. Levtchenko, A. Shumilin, in *Future Physics at HERA*, Proceedings of the Workshop, DESY, Hamburg, May 1996

[11] S.J. Brodsky, T. Kinoshita, H. Terazawa, Phys. Rev. **D4** (1971) 1532

[12] J.F. Gunion, H.E. Haber, G. Kane, S. Dawson, The Higgs Hunter's Guide, Addison-Wesley, Reading 1990

[13] M. Carena, S. Pokorski, C.E.M. Wagnet, Nucl. Phys. **B406** (1993) 59

[14] J. Ellis, G.L. Fogli, E. Lisi, Preprint CERN-TH/95-202

[15] A. Djouadi, J. Kalinowski, M. Spira, http://wwwcn.cern.ch~mspira/prog

[16] J. Kalinowski, M. Krawczyk, Phys. Lett. **B361** (1995) 66; Acta phys. Polon. **B 27** (1996) 961; M. Krawczyk, talk at Moriond'96; D. Choudhury, M. Krawczyk, Preprint MPI-PTh/96-46, IFT-96/13 (hep-ph/9607271)

[17] M. Krawczyk, B.B. Levtchenko, in preparation